Estimating the Risk of Technology Development

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When do you do risk analysis ?

Risk analysis and response planning must be done during the initial planning phase of the project. Ideally, risk analysis and response planning is done during the project proposal phase and revisited on a regular basis.

"70% of a project's cost at completion is committed by the time the first 5% of the project's budget is actually spent."

The Elements of Risk

Risk is composed of TWO elements:

1) The UNCERTAINTY (expressed as a probability (Pf) of achieving a project performance objective,

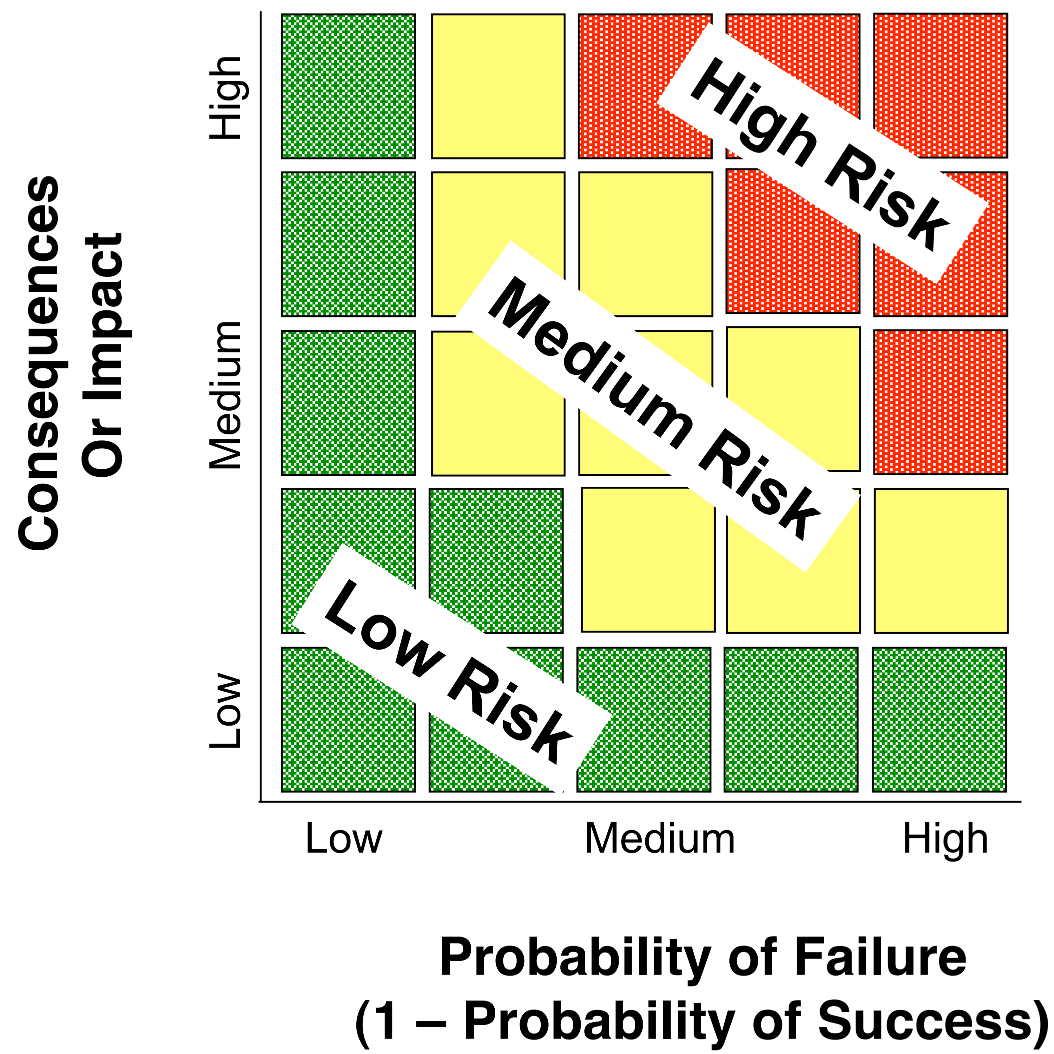
AND

2) The CONSEQUENCES (Cf) of a risk event

Risk= Pf x Cf

Caution is needed, of course in using this approach. It is necessary to be wary of multiplying 2 pieces of information together to produce a figure which may ,make an account's eyes light up but be of little practical value to a project manager.

Risk Assessment Matrix



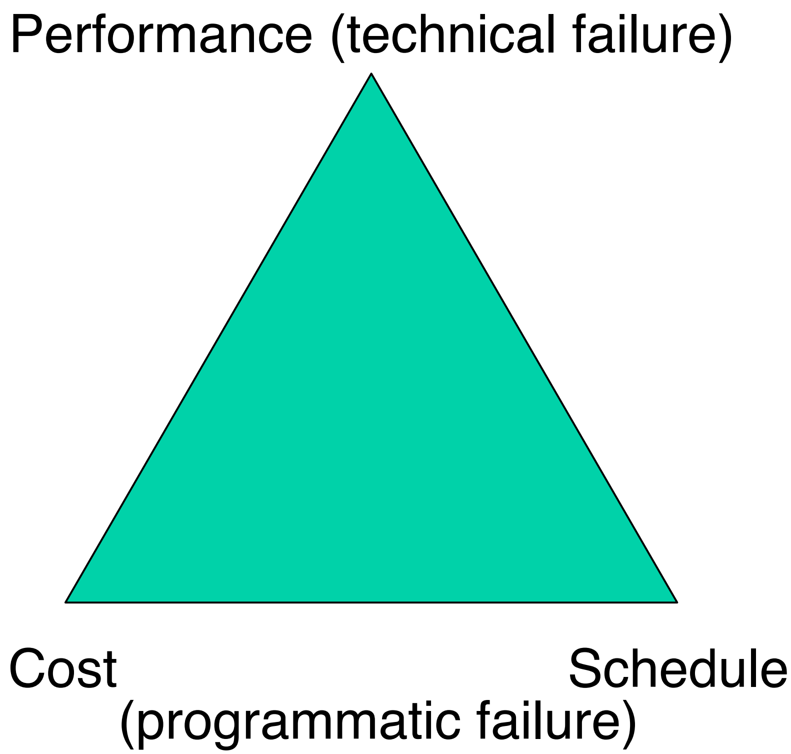
Characterization of Technology Risk
(utilization for system development)

- Probability of failure to:
  - Reach maturity for system integration (programmatic failure)
  - And meet Technical Performance Measures goals (technical failure)

- Impact on overall system performance of failing to meet TPM goals

Measures of Probability of Failure

- The Probability of Failure is measured by the three measures used for programs or projects - cost, schedule, and performance.



Measures of Programmatic Failure

- Development difficulty
  - **Technology Readiness Level Gap (Initial to TRL6)**
  - Research and Development Degree of Difficulty
  - TPM gap

- Requirements, requirements flowdown, interface requirements, etc.

- Schedule
  - Defined schedule showing maturity increasing/adequate analysis and testing
  - Critical Path
  - Adequate slack
  - High risk items, work around
  - Exit criteria for every milestone

- Cost
  - Defined cost for all milestones
  - Costs include NASA and contractor

- Management and technical team (experienced)

NASA's TECHNOLOGY READINESS LEVEL
(Scale for Tracking Risk Reduction)

9 - Actual system "flight proven" on operational flight

8 - Actual system completed and "flight qualified" through test and demonstration

7 - System prototype demonstrated in flight

6 - System/Subsystem (configuration) model or prototype demonstrated/validation in a relevant environment

5 - Component (or breadboard) verification in a relevant environment

4 - Component and/or breadboard test in a laboratory environment

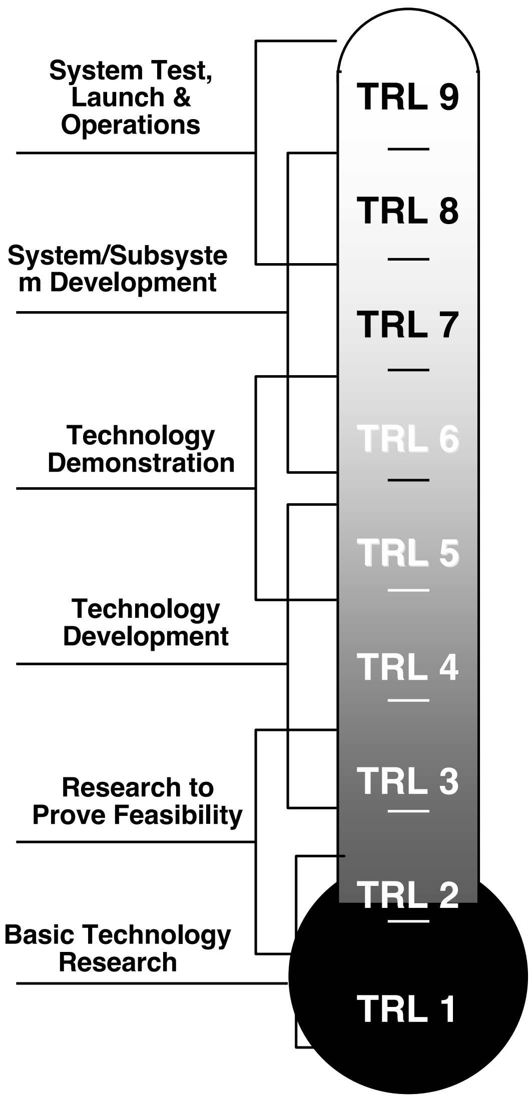
3 - Analytical & experimental critical function, or characteristic proof-of-concept, or completed design

2 - Technology concept and/or application formulated (candidate selected)

1 - Basic principles observed and reported

Technology Readiness Level of 6 is usually required for Development

NASA's
Technology Readiness Levels (Software)



TRL 9: Actual system "mission proven" through successful mission operations *Thoroughly debugged software readily repeatable. Fully integrated with operational hardware/software systems. All documentation completed. Successful operational experience. Sustaining software engineering support in place. <u>Actual system fully demonstrated.</u>*

TRL 8: Actual system completed and "mission qualified" through test and demonstration in an operational environment *Thoroughly debugged software. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. V&V completed.*

TRL 7: Initial system demonstration in high-fidelity environment (parallel or shadow mode operation) *Most functionality available for demonstration and test. Well integrated with operational hardware/software systems. Most software bugs removed. Limited documentation available.*

TRL 6: System/subsystem prototype validated in a relevant end-to-end environment *Prototype implementations on full scale realistic problems. Partially integrated with existing hardware/software systems. Limited documentation available. <u>Engineering feasibility fully demonstrated.</u>*

TRL 5: Module and/or subsystem qualified in relevant environment *Prototype implementations conform to target environment / interfaces. Experiments with realistic problems. Simulated interfaces to existing systems.*

TRL 4: Module and/or subsystem qualified in laboratory environment *Standalone prototype implementations. Experiments with full scale problems or data sets.*

TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept *Limited functionality implementations. Experiments with small representative data sets. <u>Scientific feasibility fully demonstrated.</u>*

TRL 2: Technology concept and/or application formulated *Basic principles coded. Experiments with synthetic data. Mostly applied research.*

TRL 1: Basic principles observed and reported *Basic properties of algorithms, representations & concepts. Mathematical formulations. Mix of basic and applied research.*

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Research and Development Degree of Difficulty (RD^3)

$R\&D^3$

I A very low degree of difficulty is anticipated in achieving research and development objectives for this technology.

Probability of Success in “Normal” R&D Effort > 99%

II A moderate degree of difficulty should be anticipated in achieving R&D objectives for this technology.

Probability of Success in “Normal” R&D Effort > 90%

III A high degree of difficulty anticipated in achieving R&D objectives for this technology.

Probability of Success in “Normal” R&D Effort > 80%

IV A very high degree of difficulty anticipated in achieving R&D objectives for this technology.

Probability of Success in “Normal” R&D Effort > 50%

V The degree of difficulty anticipated in achieving R&D objectives for this technology is so high that a fundamental breakthrough is required.

Probability of Success in “Normal” R&D Effort > 20%

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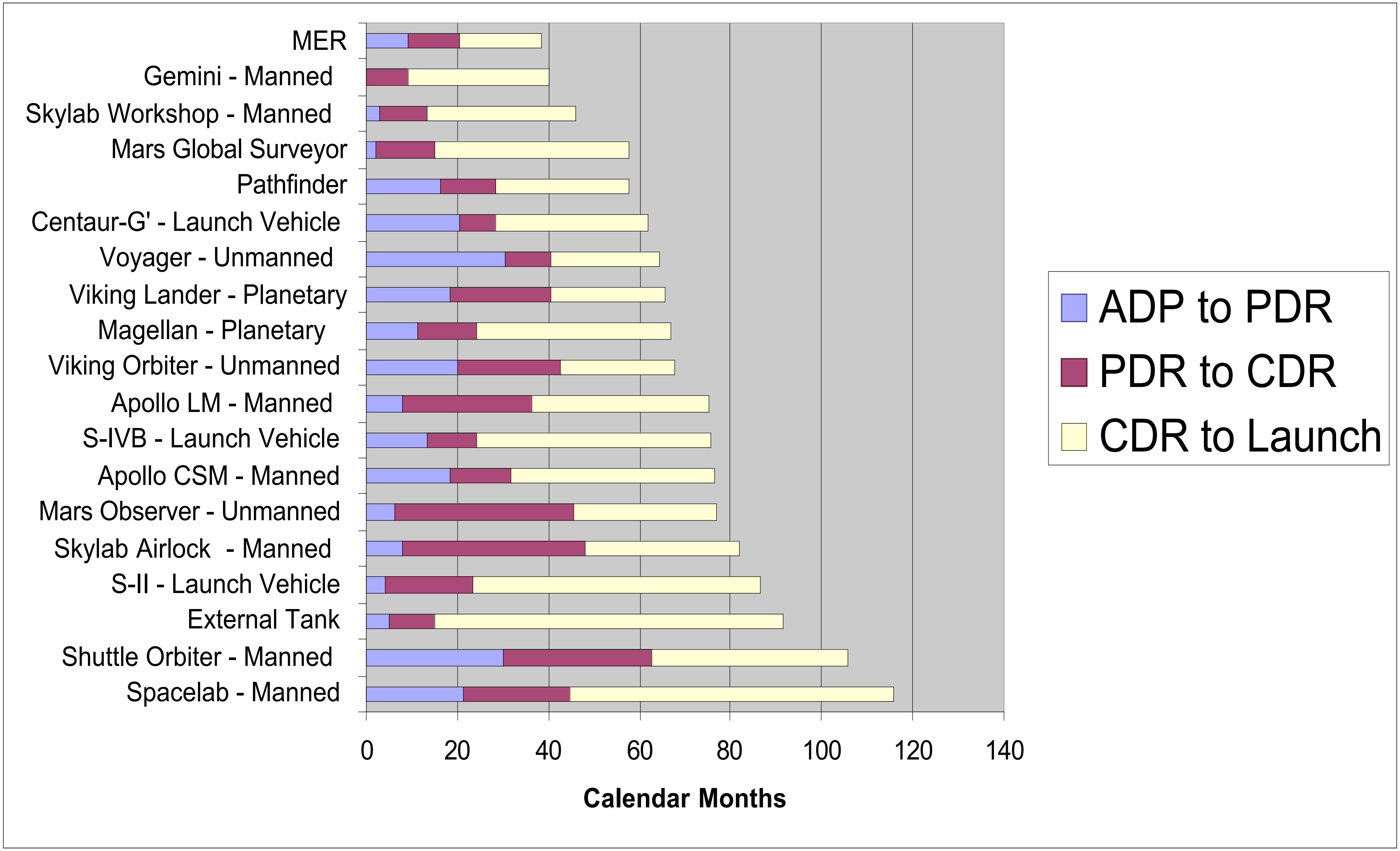
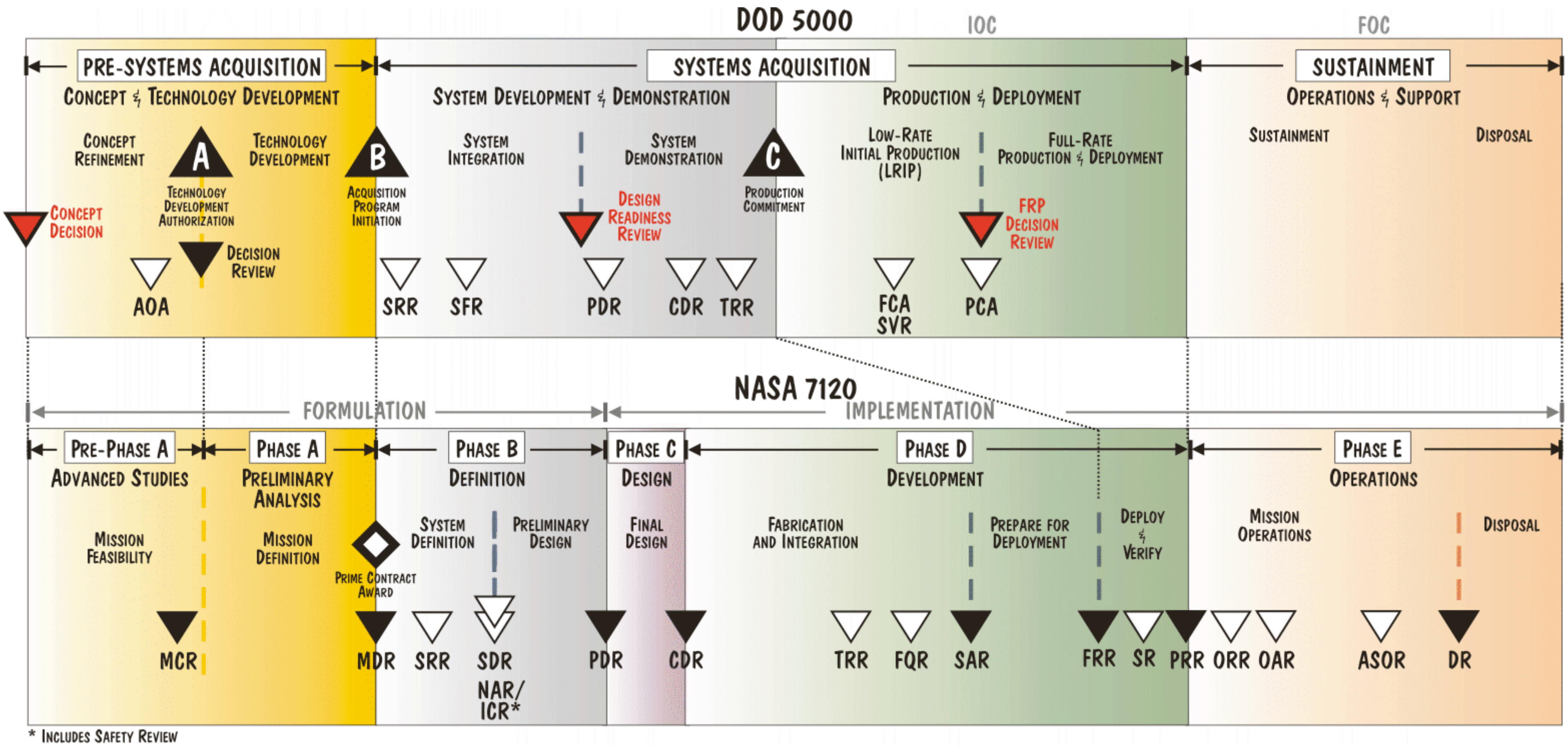
NASA Program Schedule Actuals



Life Cycle Milestones



DODI 5000.2

NASA 6105

AOA	Analysis of Alternatives	IOC	Initial Operational Capability
ASOR	Annual Systems Operations Review	MCR	Mission Concept Review
CDR	Critical Design Review	MDR	Mission Design Review
DR	Decommissioning Review	NAR	Non-Advocate Review
FCA	Functional Configuration Audit	OAR	Operational Acceptance Review
FOC	Full Operational Capability	ORR	Operational Requirements Review
FQR	Formal Qualification Review	PCA	Physical Configuraion Audit
FRR	Flight Readiness Review	PDR	Preliminary Design Review
ICE	Independent Cost Review	PRR	Production Readiness Review

SAR	System Acceptance Review
SDR	System Design Review
SFR	System Functional Review
SR	Safety Review
SRR	System Requirements Review
SVR	System Verification Review
TRR	Test Readiness Review

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- Schedule
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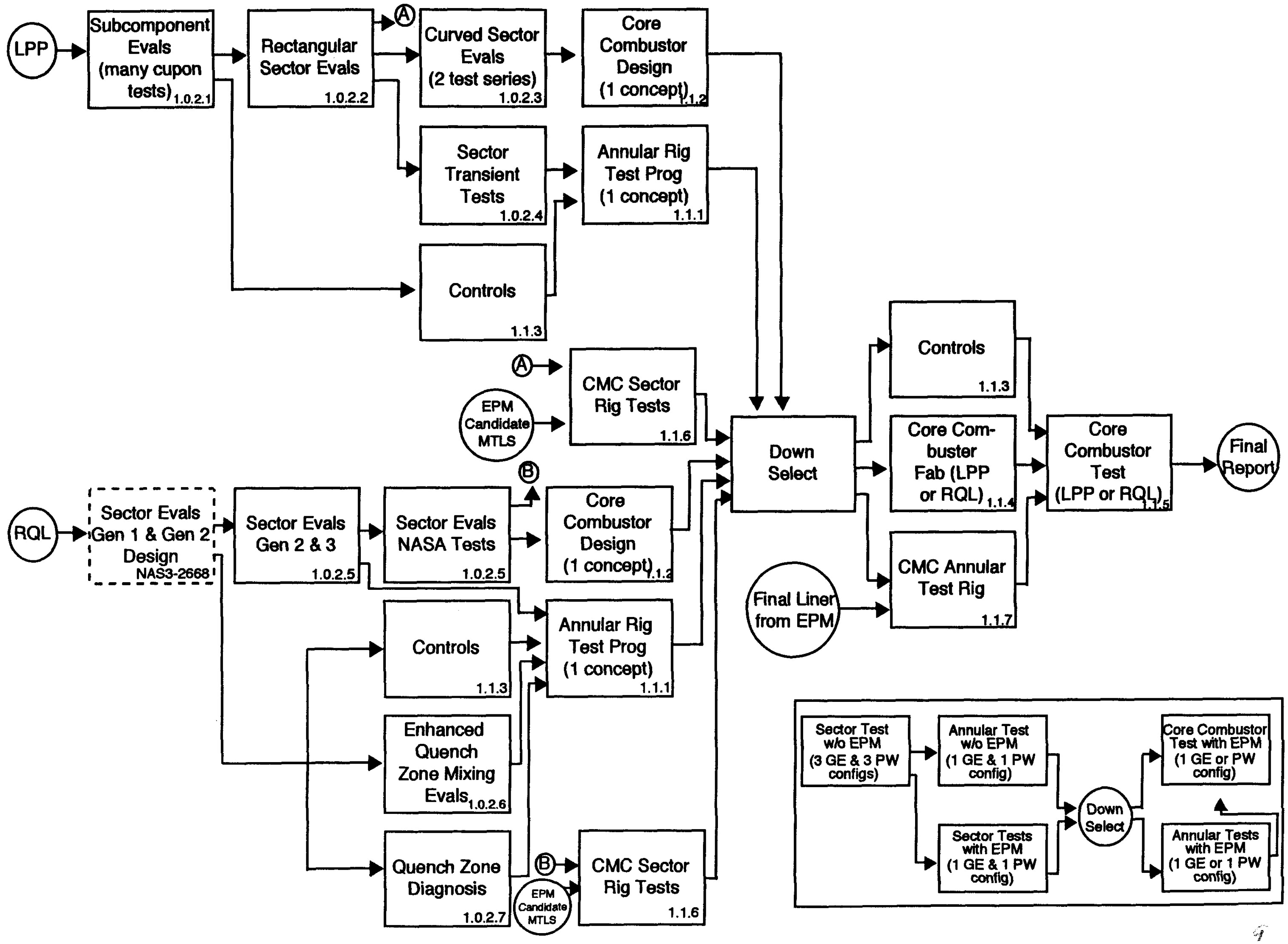
  - Adequate slack
  - High risk items, work around
  - Exit criteria for every milestone

- Cost
  - Defined cost for all milestones
  - Basis of costs (FTEs, facilities, hardware, etc.)

- Management and technical team (experienced)

Low NOx Combustor

1-Pager Work Logic



Low NOx Combustor

1-Pager Work Logic Description

1.0.2.1 LPP Subcomponent Evals

- Many cupons tested
- Feeds sector test prog
- Continues during sector test prog
- Used for sector design refinement
- Essentially complete by FY95
- GE/NASA

1.0.2.2 CPP Rectangular Sector Evals

- Combines components for integrated evals
- 3 configurations tested
- Primary feed to annular test program design
- Secondary feed to core combustor test program design
- Uses non EPM materials
- GE/NASA

1.0.2.3 LPP Curved Sector Evaluation

- Added shape fidelity over rectangular evals
- Two test series of single configuration
- Feed core combustor test program design
- GE

1.0.2.4 LPP Sector Transient Test

- Evaluation of rectangular sector configurations
- Primary feed to annular test program design

1.0.2.5 RQL Sector Combustion Rig

- 3 generation tests of progressively complex design
- Gen I tests and Gen II design from separate contract
- P&W test feed annular rig test program design
- NASA test feed core combustor test program
- Uses non EPM materials
- P&W/NASA

1.0.2.6 Inhanced Quench Zone Mixing

- Applies to RQL configuration
- P&W/NASA participation
- Feeds annular rig test program design

1.0.2.7 Quench Zone Diagonistics

- Same as 1.0.2.6
- P&W participation

1.0.2.8 Analytical Code Dev

- Feed products to test programs as developed
- NASA

1.0.2.9 Emission Minimizing Completion Controls

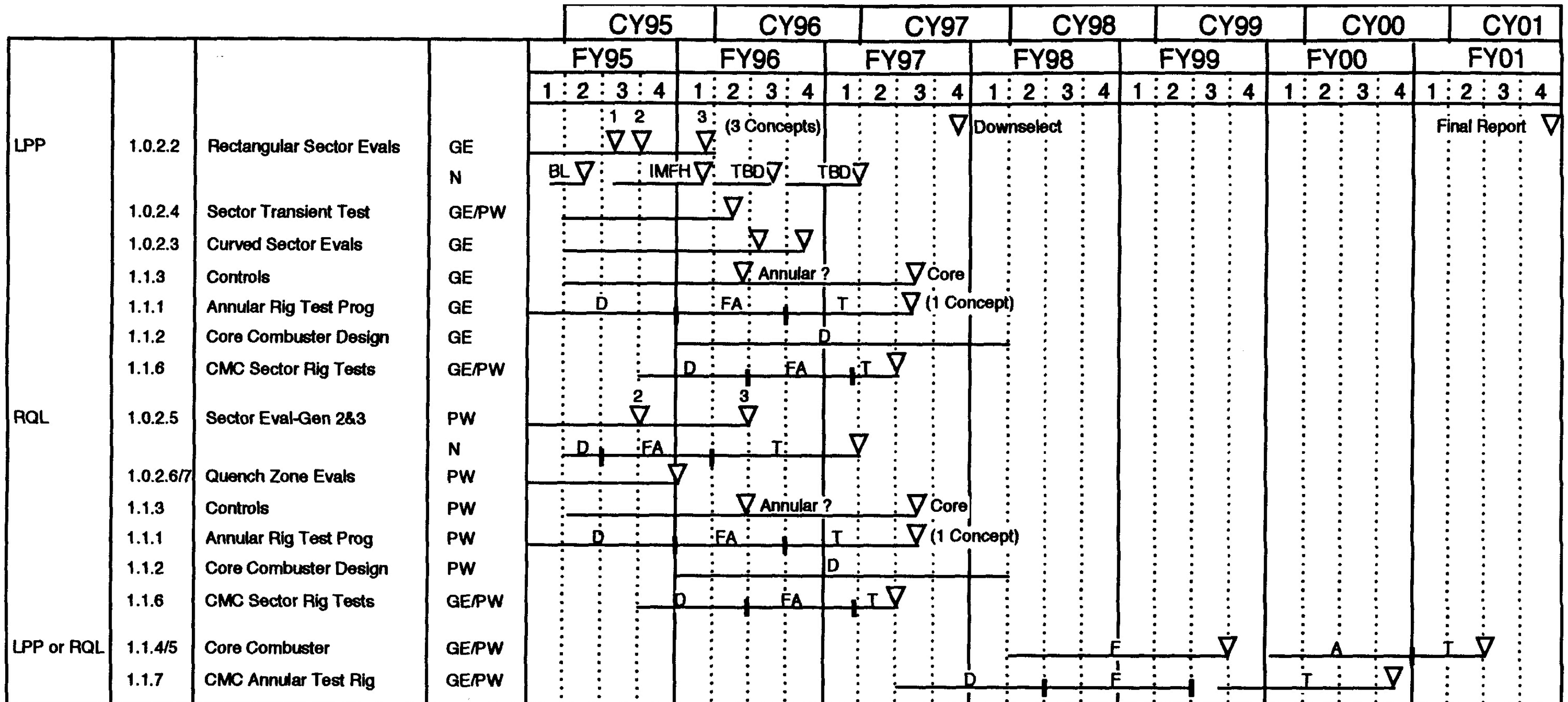
- Feed products to test programs as developed
- NASA

1.0.2.10 Grants

- Feed products to test programs as developed
- Universities

Low NOx Combustor

1-Pager Work Schedule



		FY95	FY96	FY97	FY98	FY99	FY00	FY01
Models	Designed	11	2	2				
Models	Fabed	7	7					
Tests	Completed	7	12	8				
Analysis	Completed	4	13	10				
Simulations	Completed	7	4	1				

		FY95	FY96	FY97	FY98	FY99	FY00	FY01	Total
1.0.2	Combuster Supporting Tech Tests	9.4	6.0	2.0	1.2	1.1	.1		19.8
1.1.1	Annular Rig Test Prog	7.1	9.5	1.9					18.5
1.1.2	Core Combuster Design	.4	4.5	5.6	1.8	.9	.7	.5	14.5
1.1.3	Controls	1.4	1.1	.9	.7	1.0	.9	.3	6.3
1.1.4	Core Combuster Fab				.6	2.6	.5		3.8
1.1.5	Core Combuster Assy & Test				.6	1.2	7.2	4.5	13.5
1.1.6	CMC Sector Rig Tests	.3	.9	1.7					3.0
1.1.7	CMC Annular Rig Tests		.3	.9	.7	2.8	1.5	.1	6.3
	Total	18.6	22.3	13.0	5.5	9.6	10.9	5.4	85.7

Low NOx Combustor

1-Pager Cost Distribution

			94	95	96	97	98	99	00	01	02	Total
1.0.2	Combustor Supt Tech	P	.3	3.6	.4	-	-	-	-			4.2
		G	-	2.5	2.5	-	-	-	-			5.0
		N	-	3.3	3.1	2.0	1.2	1.1	.1			10.8
		T	.3	9.4	6.0	2.0	1.2	1.1	.1			20.1
1.1.1	Annular Combustor Rig	P	.4	2.9	2.6	.4	-	-	-			6.3
		G	.2	4.3	6.8	1.5	-	-	-			12.9
		N	-	-	-	-	-	-	-			-
		T	.6	7.1	9.5	1.9	-	-	-			19.2
1.1.2	Core Combustor Design	P	-	.2	3.0	3.6	1.1	.8	.6	.4	-	9.9
		G	-	.2	1.5	2.0	.7	.1	.1	.2	-	4.6
		N	-	-	-	-	-	-	-	-	-	-
		T	-	.4	4.5	5.6	1.8	.9	.7	.5	-	14.5
1.1.3	Low NOX Combustor Controls Dev	P	-	.4	.5	.6	.4	1.0	.9	.3	-	4.0
		G	.1	.8	.4	.1	.2	-	-	-	-	1.6
		N	-	.2	.2	.2	.1	-	-	-	-	.7
		T	.1	1.4	1.1	.9	.7	1.0	.9	.3	-	6.3
1.1.4	Core Engine Combustor Fab	P	-	-	-	-	.5	1.0	.5	-	-	2.1
		G	-	-	-	-	.1	1.6	-	-	-	1.7
		N	-	-	-	-	-	-	-	-	-	-
		T	-	-	-	-	.6	2.6	.5	-	-	3.8
1.1.5	Core Engine Test	P	-	-	-	-	.5	.1	3.4	3.3	-	7.3
		G	-	-	-	-	.1	.2	.3	.1	-	.6
		N	-	-	-	-	-	.9	3.5	1.0	.1	5.5
		T	-	-	-	-	.6	1.2	7.2	4.5	.1	13.5
1.1.6	CMC Combustor Sector Rig	P	-	.3	.7	1.6	-	-	-	-	-	2.7
		G	-	-	.2	.1	-	-	-	-	-	.3
		N	-	-	-	-	-	-	-	-	-	-
		T	-	.3	.9	1.7	-	-	-	-	-	3.0
1.1.7	CMC Annular Combustor Rig Test	P	-	-	.1	.1	-	.2	.2	-	-	.7
		G	-	-	.2	.8	.7	2.6	1.3	.1	-	5.6
		N	-	-	-	-	-	-	-	-	-	-
		T	-	-	.3	.9	.7	2.8	1.5	.1	-	6.3
	Total	P	.7	7.4	7.3	6.3	2.5	3.1	5.6	4.0	-	36.9
		G	.3	7.8	11.6	4.5	1.8	4.5	1.7	.4	-	32.6
		N	-	3.52	3.5	2.2	1.3	2.0	3.6	1.0	.1	17.2
		T	1.0	18.6	22.3	13.0	5.6	9.6	10.9	5.4	.1	86.7

Minimal Technology Data Sheet

Contact Information

Person Providing Data:		Secondary Contact:	
Phone:		Phone:	
Email Address:		Email Address:	

Capability:	
Capability Impact:	(see chart 1-10)
Impact Rationale:	

Technology Project Name:

Description	Objectives,Scope, State of the Art and Improvements to SOA (Gap assessment), Heritage of Technology (evolution or revolution path)
Technology Maturity	
Current TRL (1-6)	(List/Describe Characteristics of Technology or Your Rationale for Qualifying it at the TRL noted.)
Time to mature to TRL=6, yrs	(use technology development schedule to show TRL progression)
Total cost to obtain TRL=6	(full cost including workforce, contracts, hardware, infra-structure, test facilities use and/or improvements, etc
Research Degree of Difficulty (1-5)	(List/Describe Characteristics of Technology or Your Rationale for Qualifying it at the RD^3 noted.)

Dependence on other technologies to meet capability expectations

Technologies	Developers	Funded or Unfunded

Technical Performance Measures	State of Art Value	Projected Value	Probability
(e.g. weight, power, etc.) and Units		Value at end of development program.	Probability of meeting performance by technology development date.

Technology Development Schedule

Year	Milestone	TRL	Cost

Impact

Cost and Credibility

Difficulty

Meets architecture ATP schedule

Assessing Technology Risk Using AHP (Analytical Hierarchical Process)

- The AHP is based on the hierarchical decomposition of the prioritization or forecasting criteria down to the level at which the decision or forecast alternatives can be pair-wise compared for relative strength against the criteria.

- The pair-wise comparisons are made by the participating experts and translated onto a numerical ratio scale.

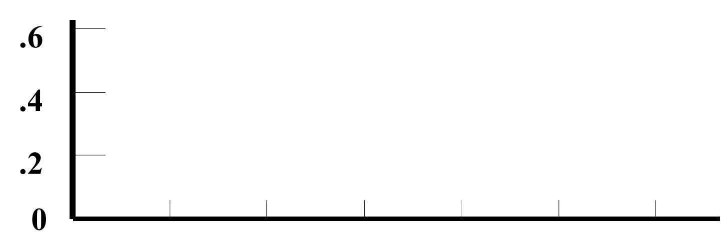
- The AHP mathematical model then uses the input pair-wise comparisons data to compute priorities or forecast distributions as appropriate.

Analytical Hierarchical Process

Individual Assessment

Metric Interval	Most Likely	Relative Likelihood	
20 to 25 Units		5%	As likely as 35 to 40
25 to 30		25%	As likely as 35 to 40
30 to 35		75%	As likely as 35 to 40
35 to 40		100%	Most likely interval
45 to 50		10%	As likely as 35 to 40

Integrated Group Assessment



TECHNOLOGY RISK ASSESSMENT – PHASE 3
SUMMARY OF AIRFRAME RISK ASSESSMENTS

TA	TECHNOLOGY PROJECT	COST	SCHED	TECH
2	STRUCTURAL HEALTH MONITORING – NORTHROP GRUMMAN			
2	METALLIC CRYOTANK - BOEING			
2	CERAMIC MATRIX HOT STRUCTURES - MRD			
2	DURABLE ACREAGE CERAMIC TPS - BOEING			
2	DURABLE ACREAGE METALLIC TPS - OCEANEERING			
2	INTEGRATED AERO-THERMAL & STRUCTURAL THERMAL ANALYSIS - NASA			
2	STRUCTURAL & MATERIALS/TANK/TPS INTEGRATION - NASA			
2	STAGE SEP & ASCENT AERO-THERMODYNAMICS - NASA		No Data	
2	MATERIALS & ADVANCED MANUFACTURING: PERMEABILITY RESISTANCE - NASA			
2	LIGHTWEIGHT INFORMED MICRO-METEOROID RESISTANT TPS - NASA			
2	ULTRA HIGH TEMPERATURE SHARP EDGE TPS - LMC			
2	CERAMIC MATRIX COMPOSITE – SOUTHERN RESEARCH			

TECHNOLOGY RISK ASSESSMENT – PHASE 3
STRUCTURAL HEALTH MONITORING (SHM)

TA-2 Airframe | **Northrop Grumman**

MAJOR RISKS

Cost – Cost of 8,000 sensors for full scale SHM could be very high, but is understood.

Schedule – Critical schedule issue is availability of Composite Cryo-tank for testing. SHM starting at TRL 4 in 2002. No development issues affecting schedule.

Technical

- Reliability – Integration of 8,000 sensors into one reliable SHM is a risk
- Testability - Availability of Full Scale Composite Cryo-tank for testing to achieve TRL 6

CONTINGENCY PLAN SUGGESTION

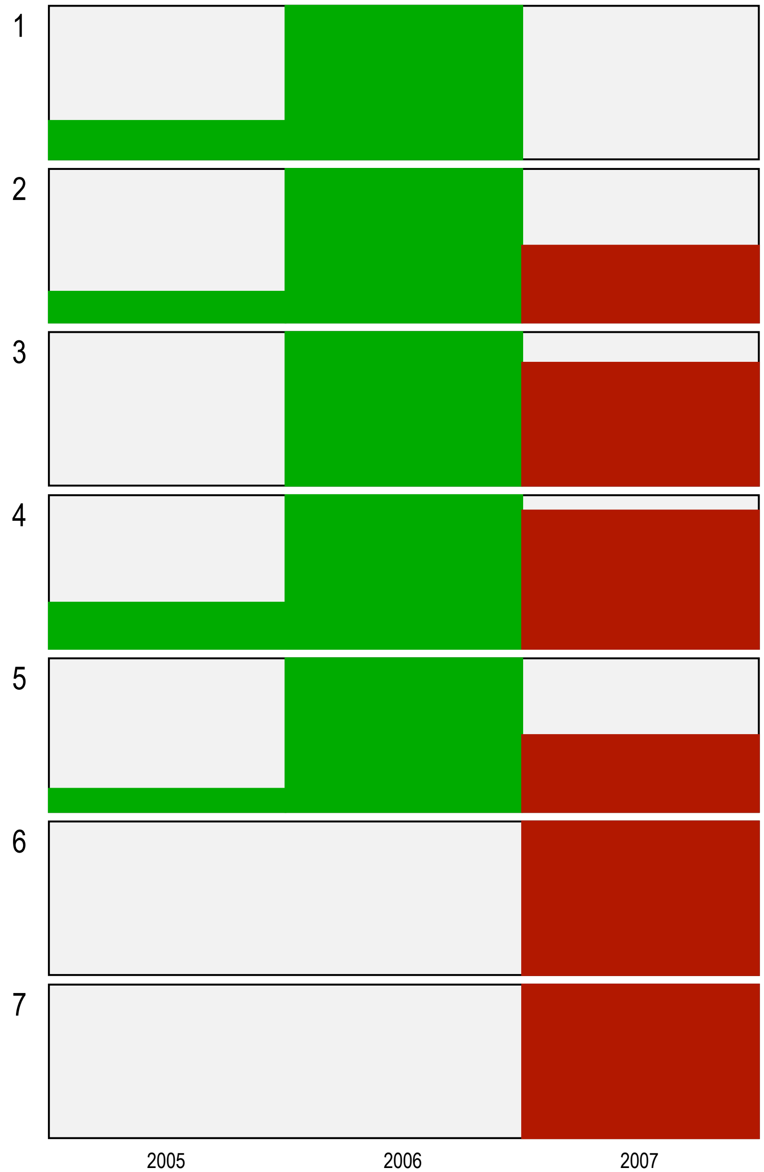
Use a subscale tank (18 to 20 ft diameter) to test SHM system

NOTE: Only new or updated comments are contained in this report. Refer to Phase 2 report for complete evaluation. No significant change in evaluation from Phase 2.

Show Stopper – Lack of Funding for Composite Cryo-tank for Testing

Structural Health Monitoring (Northrop Grumman)

Development Schedule



Goal: 2006 years

1: They should meet this goal based on present information.

2: NGC is starting with the SHM technology at a TRL level of 4 in 2002. They have plans to develop a structural health monitoring system and integrate it into a full-scale composite cryotank and complete test in 2005 timeframe. So the critical element of this is really having available a full-scale composite tank with this system integrated into it in 2005. That's the biggest concern because the funding level could get cut on the full-scale development of a composite tank that is in a separate technology development/funding under GEN2. So, there are no major issues with respect to developing the SHM system that NGC is proposing here. The issue is with respect to the availability of a full-scale composite cryotank in 2005/2006 which could face some serious funding issues given that GEN2 is probably not going to carry two tanks to TRL = 6 (metallic and composite).

5: If funding is maintained for the duration of the project, it is probable that it will come in on schedule.

7: There is a trade-off that should be made between the amount of health monitoring and robustness of design/analysis. As the vehicle is used for repeated flights some of the health monitoring sensors will become inoperable and others will produce data that has increasing errors. At some point a decision will need to be made relative to how many flights can be achieved before the health monitoring system itself must be inspected and checked out for adequate performance. The cost of maintaining the health monitoring system should be weighed against the cost of increasing the robustness of design thereby reducing the need for health monitoring. The reliability of the health monitoring system must consider the sensors, the data system and everything that is needed to transfer the data from the sensor to the data system. The lowest reliability part of the system may be the vehicle installed data transmission lines (quite a nest of lines) which must pass through the vehicle requiring compromises to be made in other disciplines of the vehicle design.

Technology Success Data

Technology Area: Airframe Technologies
Technology Development: Composite Cryotank (Northrop Grumman)

Probability of Success

Metric	Units	Weight	Low	High	Goal	EV	EV Dev.[1]	Success
Development Cost	Million $	0.50	85	235	115	137	-19%	12%
Development Schedule	years	0.50	2005	2007	2006	2006.9		50%
[2] **Weighted Programmatic Success:**	31%							
External Inspection Interval	missions	0.09	0	200	125	86	-31%	30%
Flight Mission Life	missions	0.13	0	500	400	232	-42%	15%
Internal Inspection Interval	missions	0.09	[illegible]	120	60	42	-30%	26%
Leak Rate	SCIM	0.11	0	1200	200	399	-100%	28%
Operating Pressure	PSI	0.11	10.0	50.0	30.0	30.7	2%	58%
Reliability	%	0.11	99.99900	100.00000	99.99950	99.99952	0%	52%
Weight/Volume	lb/cu ft	0.13	0.100	0.900	0.220	0.376	-71%	13%
[2] **Weighted Technical Success:**	31%							
[3] **Combined Weighted Success:**	31%							

Expected Value – Mean or average value of the estimated probability distribution. It is the value of the metric expected by the evaluators

Expected Value Deviation – Deviation of the EV from the goal, calculated as follows:

Absolute Value: $\dfrac{\text{EV} - \text{Goal}}{\text{Goal}}$

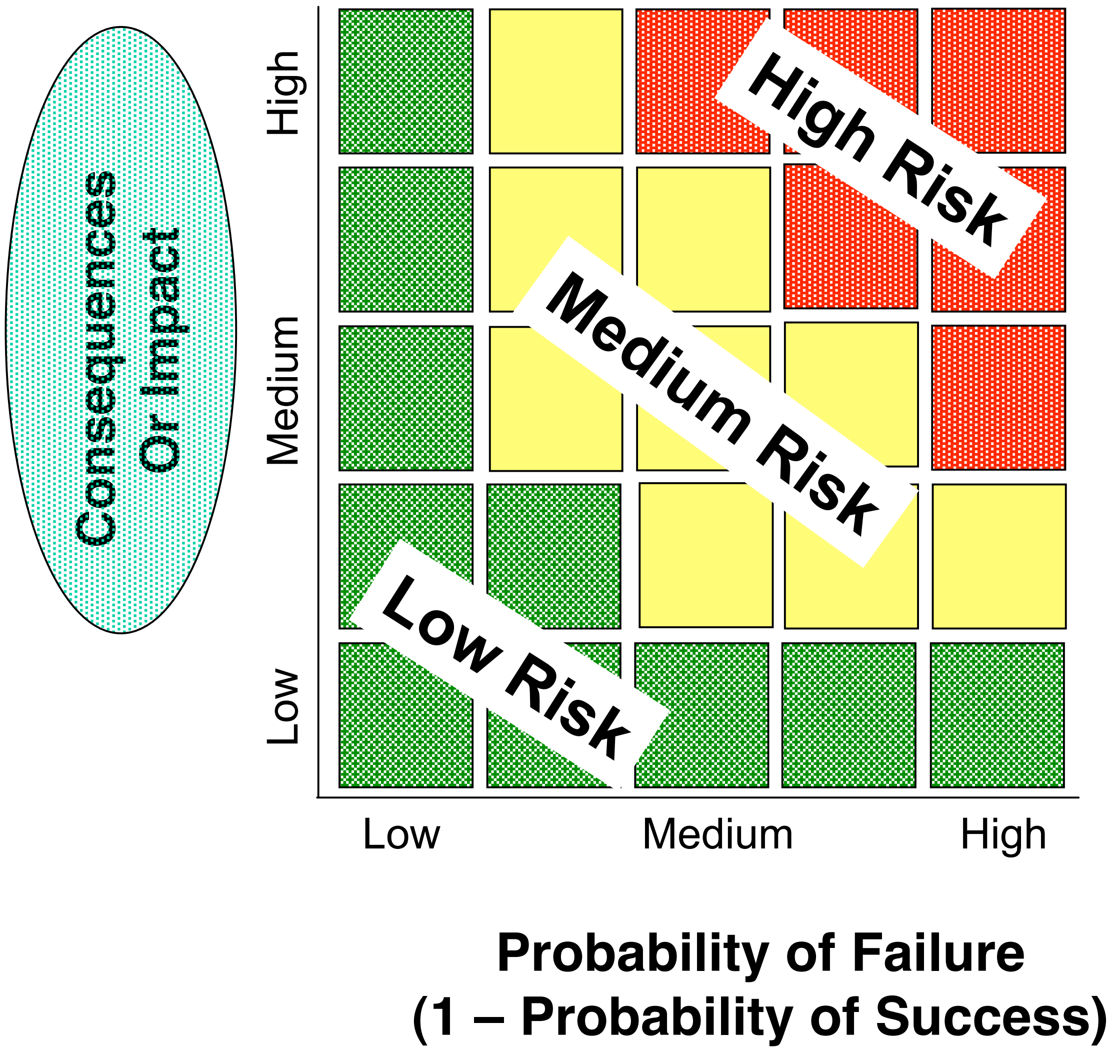
A minus sign in front of the calculated value indicates that the EV is worse than the goal.

Assumption: The Low to High range contains 100% of the possible values of the metric.

[1] EV Deviation show by how much the EV misses the goal. It is omitted for certain metrics.
[2] Weighted Success is the average success probability of the metrics.
[3] Combined Weighted Success is average of technical and programmatic Weighted Success.

0% - 20% | 20%-50% | 50%-100%

Risk Assessment Matrix



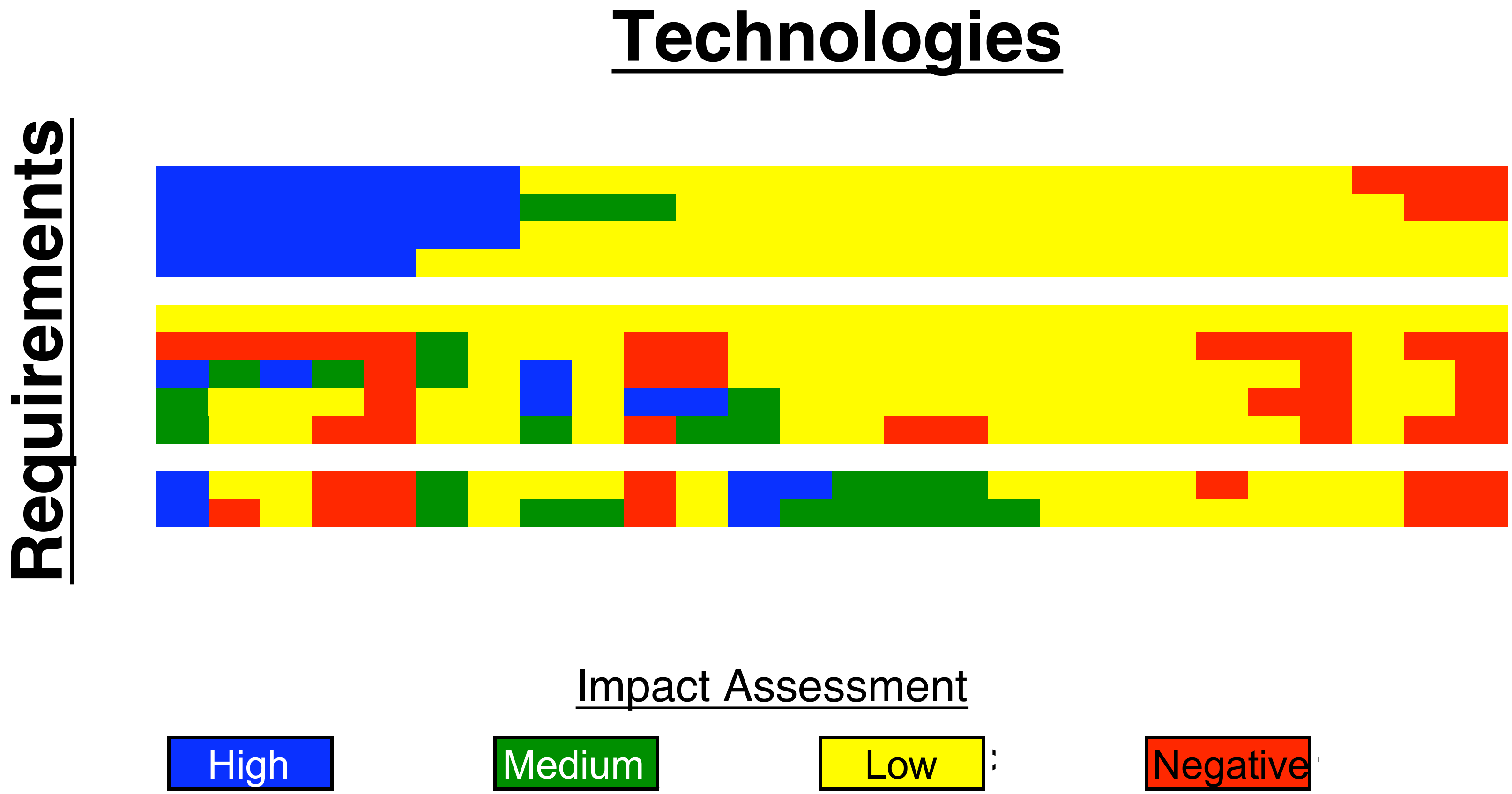
Launch Vehicle Propulsion Technology Selection

	Delta Isp, sec	Cost	Delta Isp/Cost	TRL	RD^3	Probability of Failure
Metalized Hydrogen	15	200	0.075	2	5	25
Advanced Materials	10	150	0.067	3	4	16
Chamber Pressure	8	100	0.080	3	4	16
Combustion Efficiency	6	90	0.067	4	3	9
Nozzle Efficiency	4	50	0.080	4	2	6
O/F Ratio	2	65	0.031	5	2	4

What is the your investment order?

Weighted Technology Impact Ranking

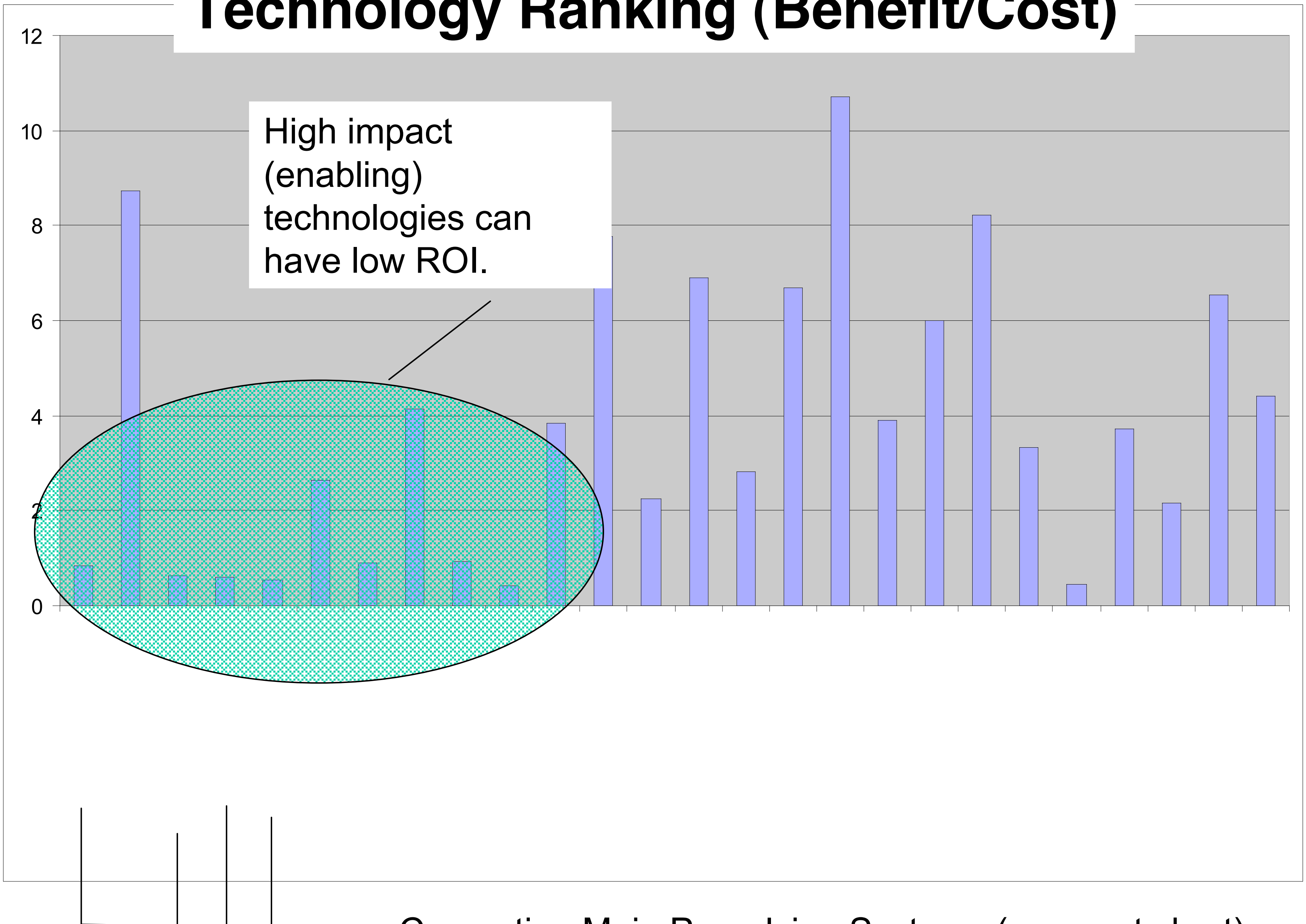
(Quantitative assessment after tech portfolio selected and funded)



Comments on Investment Strategy and Impact Assessment Method

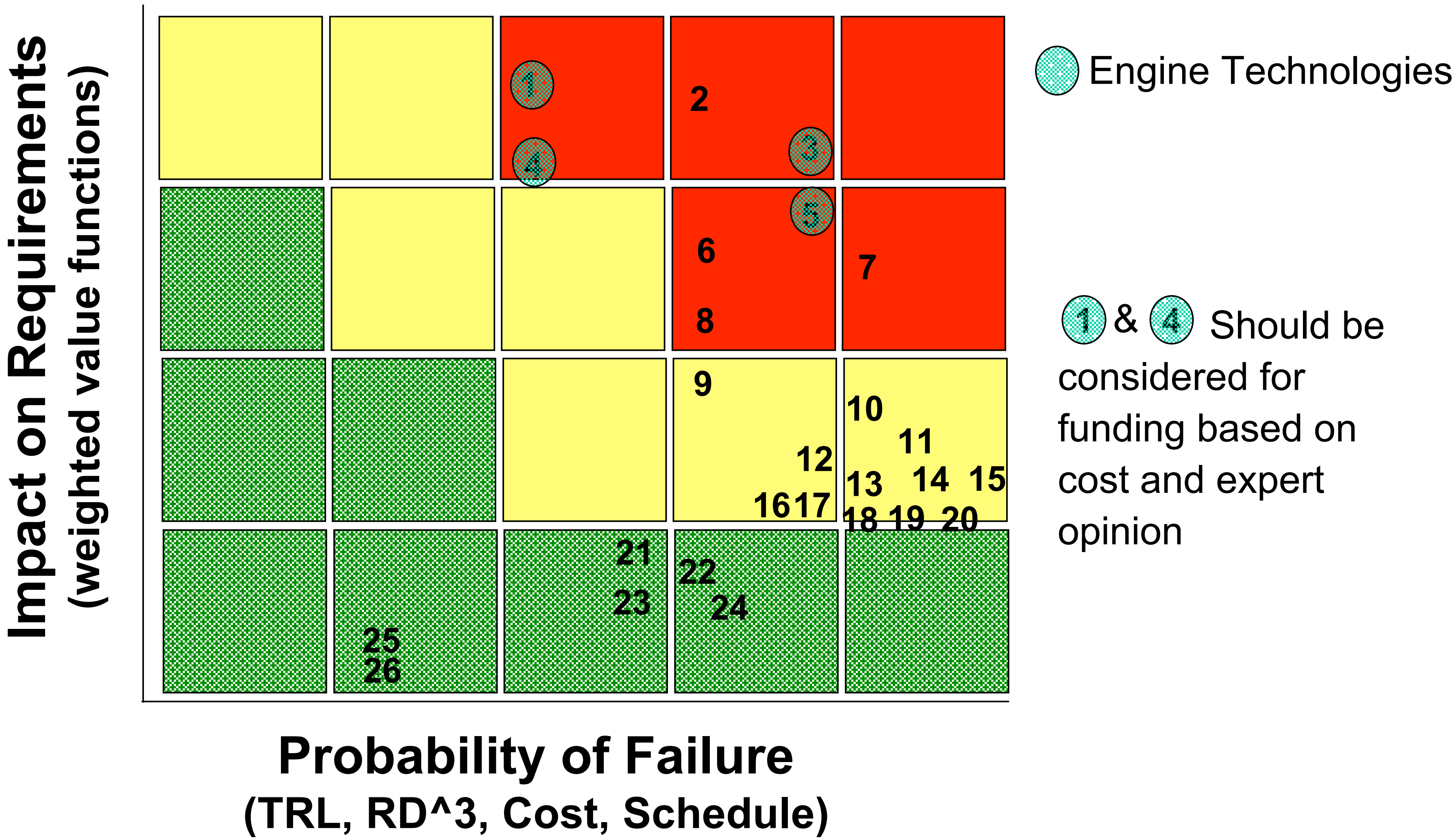
- Very poor choice of technology portfolio (~two-thirds of technologies have low or negative impact)
- Wrong requirements were developed
- Systems analysis did not model the technologies correctly

Technology Ranking (Benefit/Cost)

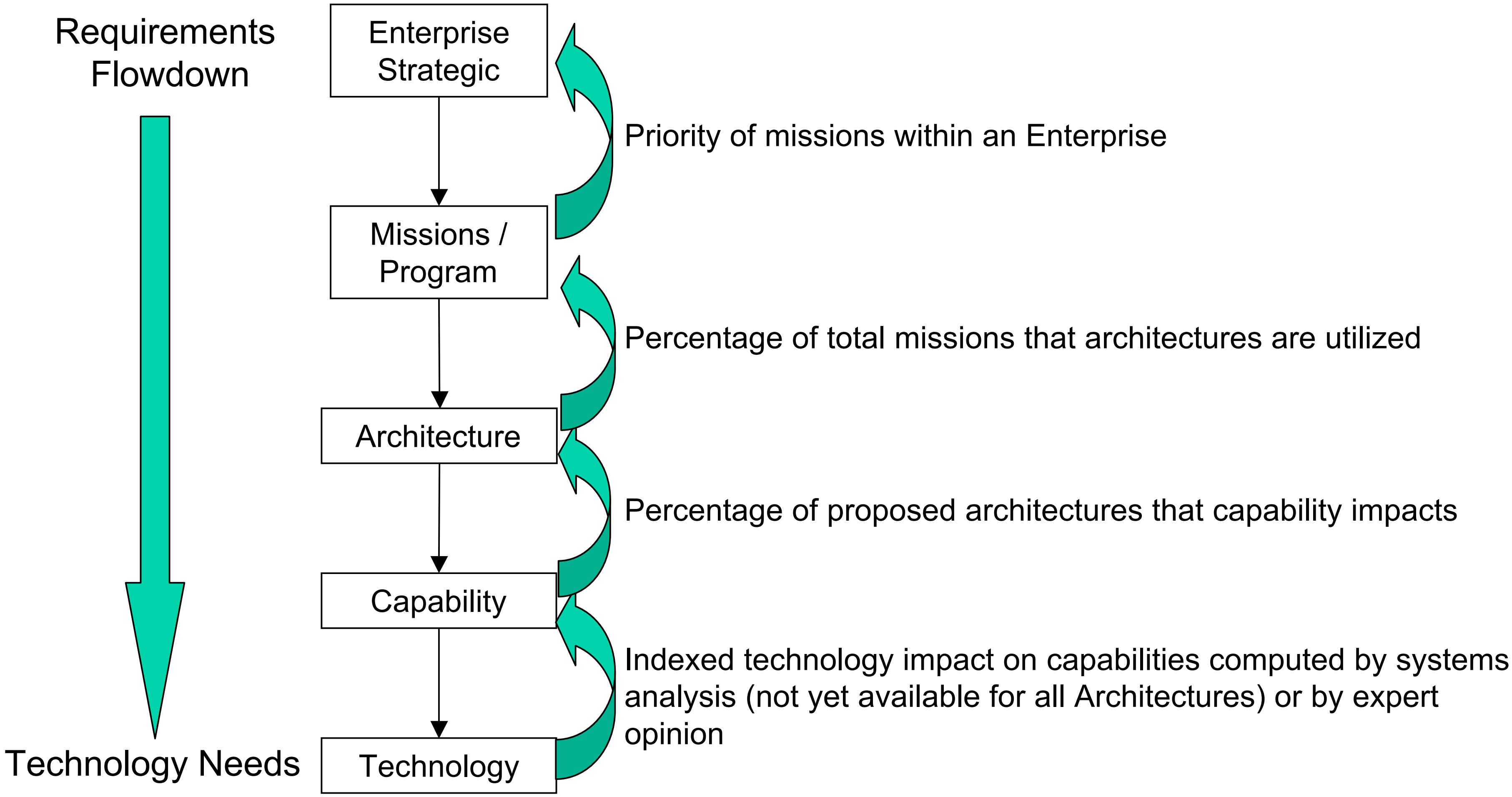


Competing Main Propulsion Systems (see next chart)

Technology Risk Assessment



Technology Agency Impact Model



$$\text{Technology Impact} = \text{Capability Impact} * \text{Architecture Impact} * \text{Mission Impact} * \text{Enterprise Impact}$$

Summary
Technology Risk Assessment

- Technology risk is based on the probability of technology development success versus the impact of the technology on the system

- Technology development probability of failure is similar to any project. Should have defined WBS, requirements, schedule, cost, etc.

- Expert opinion is used for assessment; AHP is one method to obtain and integrate the opinions.

- Expert opinion or systems analysis can be used to define the impact of the technology on the system.

- For total Agency impact, future enterprise missions need to be prioritized to assess technology global impact and risk.